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The purpose of this report is to summarize all external yield data not yet published. Previous yield measurements have been reported in MTA Quarterly Progress Reports UCRL-1009, -1137, -1436, -1573, -1903, -2194, and UCRL-2318. A complete description of the $MnSO_4$ tank method and a summary of earlier yield measurements is given in UCRL-2063, which should be consulted for details of the measurements and for a discussion of possible systematic errors. All yield values quoted herein are uncorrected for any systematic errors except background as noted.

The work reported was done under the supervision of Dr. C. M. Van Atta and with the assistance of F. Adelman, W. Birnbaum, D. Hicks, J. Ise, Jr., R. Main, R. Pyle, L. Schecter, and M. Whitehead.

320-Mev Deuterons

The yields for deuterons of approximately 320 Mev were measured using the deuterons produced by stripping He^3 ions. The energy of the deuterons was checked by determining the Bragg curve for two runs spaced 9 months apart; on these runs 4 and 6 measurements were made giving respective averages of

9.12 ± 0.29 and 9.77 ± 0.27 neutrons per incident deuteron for a 10-1/8 x 12 x 12-inch uranium target. The mean energy was 315 ± 10 Mev for both runs. (See Ise, Pyle, Hicks and Main, Rev. Sci. Instr. 25, 437 (1954) for a description of the beam so obtained.) The "background" measured with no target in the tunnel and with the $MnSO_4$ plug removed from the beam was about 10 percent of the above numbers but was not subtracted (see UCRL-2194, p. 12), since it is not believed to represent the background present when the target is in position. In addition, the "background" was measured once with the cyclotron operating and with the target in position but with the steering magnet current off so accelerated charged particles could not directly reach the cave; this background was entirely negligible.

The uncertainty in the beam monitor is greater than normal since the ion chambers could not be directly calibrated (low beam intensity). Instead the ratio of dE/dx at 190 and 320 Mev was calculated from the Range-Energy Curves of Aron, Hoffman, and Williams (AECU-663) and the multiplication of the chamber at 320 Mev calculated from the calibrated multiplication at 190 Mev. One calibration was performed and gave satisfactory agreement with the calculated ratio.

The following table lists the best values of the yields measured by the $MnSO_4$ tank for this beam. (The measurements made in the 12-inch tank may be systematically higher than those made in the 18-inch tank because of the increased neutron leakage.) For targets less than one range thick, the background was subtracted as in UCRL-2194, p. 12.

Table I

Yields for 320-Mev Deuterons

Target (inches)		Yield (neutrons per Incident deuteron)	Tank Used
Uranium	10-1/8 x 12 x 12	9.1 ± 0.3	18-inch
Uranium	10-1/8 x 12 x 12	9.8 ± 0.3*	18-inch
Uranium	1/2 x 12 x 12	2.16 ± 0.10	18-inch
Uranium	1 x 12 x 12	4.50 ± 0.15	18-inch
Carbon	8 x 24 x 24	1.2 ± 0.2	12-inch
Carbon +	8 x 24 x 24		
Uranium	10-1/8 x 24 x 24	4.3 ± 0.2	12-inch
Beryllium	9 x 24 x 24	1.9 ± 0.2	12-inch

* This value is based on a direct calibration of the ionization chamber with the 320 Mev deuteron beam.

Neutrons

Yields for various targets in the 90- and 160-Mev neutron beams have been measured and are described in somewhat more detail in UCRL-2706. The results are listed in the following table (with measured backgrounds subtracted). The 18-inch $MnSO_4$ tank was used in all measurements. Only one run was made for each target.

Table II

Yields for 90- and 160-Mev Neutrons

Target (inches)		Yield (neutrons per incident neutron)
A. 90-Mev Neutrons		
Uranium	1/2 x 6 x 6	1.23 ± 0.12
Uranium	1 x 6 x 6	2.33 ± 0.24
Uranium	1 x 12 x 12	2.37 ± 0.25
Uranium	1-1/8 x 12 x 12	2.77 ± 0.28
Uranium	3-3/8 x 12 x 12	7.32 ± 0.74
Uranium	6-3/4 x 12 x 12	10.7 ± 1.1
Uranium	10-1/8 x 12 x 12	12.2 ± 1.2
Uranium	14-5/8 x 12 x 12	12.7 ± 1.3
Cadmium	1-3/8 x 4 x 4	0.46 ± 0.05
Copper	2-5/8 x 4 x 4	0.85 ± 0.09
Copper	1-5/16 x 4 x 4	0.41 ± 0.04
Aluminum	4-1/4 x 4 x 4	0.24 ± 0.02
Carbon	6-13/16 x 4 x 4	0.29 ± 0.03
B. 160-Mev Neutrons		
Uranium	2-1/4 x 12 x 12	6.2 ± 0.6
Uranium	5 x 12 x 12	10.8 ± 1.1
Uranium	9 x 12 x 12	16.0 ± 1.6
Uranium	15-3/4 x 12 x 12	17.5 ± 1.8

490-Mev He^3 Particles

One run was made with the deflected 490-Mev He^3 beam. One run was made on each of the following targets with the exception of uranium, for which two runs were made. The first two targets are differential and the background has been subtracted as above; the last two are greater than a range. The ionization-chamber multiplication was calibrated against a Faraday cup. The 18-inch tank was used.

Table III

Yields for 490-Mev He^3 Particles

Target		Yield (neutrons per incident He^3)
Cadmium	6.101 gm/cm^2, 4 x 4 in	0.35 ± 0.04
Cadmium	12.24 gm/cm^2, 4 x 4 in	0.71 ± 0.07
Tantalum	28.75 gm/cm^2, 3 x 4 in	1.80 ± 0.2
Uranium	54.15 gm/cm^2, 3 x 3 in	3.26 ± 0.21

340-Mev Protons

Several differential targets were used with the 340-Mev proton beam. The measured yields with the background subtracted as above are given in the following table. The target dimensions were 4 x 4 in. except: thorium, 4-1/4 in. dia. cylinder; uranium, 3 x 3 in. The 18-inch tank was used.

Table IV

Yields for 340-Mev Protons

Target		Yield (neutrons per incident proton)	No. of Runs
Aluminum	28.77 gm/cm^2	0.328 ± 0.040	1
Aluminum	57.53 "	0.666 ± 0.042	3
Copper	29.93 "	0.631 ± 0.040	1
Copper	59.82 "	1.17 ± 0.04	3
Cadmium	30.71 "	1.11 ± 0.04	1
Cadmium	61.43 "	1.91 ± 0.10	2
Thorium	32.45 "	1.90 ± 0.10	1
Thorium	62.14 "	3.83 ± 0.24	3
Uranium	62.35 "	4.38 ± 0.19	2
Uranium	1/2 x 3 x 3 in	1.79 ± 0.07	2
Uranium	1 x 3 x 3 in	3.71 ± 0.12	2
Uranium	2 x 3 x 3 in	6.40 ± 0.19	2
Uranium	3 x 3 x 3 in	8.29 ± 0.28	2
Uranium	6 x 3 x 3 in	8.90 ± 0.27	2
Uranium	12 x 3-3/8 x 3-3/8 in	9.10 ± 0.27	2

190-Mev Deuterons

The yield data for 190-Mev deuterons are conveniently broken into two parts: differential (less than one range), and laterally "infinite" (24 x 24 in. or greater) targets. Yields for differential targets were measured in the 18-inch tank; those for laterally infinite targets, in the 12-inch tank.

Table V

Differential Target Yields for 190-Mev Deuterons
(background subtracted)

Target		Yield (neutrons per incident deuteron)	No. of Runs
Uranium	1/16 x 2 x 2 in	0.266 ± 0.013	2
Uranium	1/8 x 2 x 2 in.	0.503 ± 0.025	2
Uranium	1/4 x 2 x 2 in.	1.04 ± 0.05	1
Uranium	1/2 x 2 x 2 in.	1.92 ± 0.10	1
Uranium	5/8 x 2 x 2 in.*	2.30 ± 0.12	1
Uranium	1 x 2 x 2 in.*	2.42 ± 0.12	1
Uranium	2 x 2 x 2 in.*	2.73 ± 0.13	1
Uranium	3 x 2 x 2 in.*	2.88 ± 0.14	1
Carbon + Uranium	4 x 4 x 4 in. 10-1/8 x 12 x 12 in.*	1.83 ± 0.07	2
Uranium	12.07 gm/cm² x 3 x 3	1.02 ± 0.05	5
Thorium	14.82 gm/cm² x 4-1/4 dia.	1.10 ± 0.08	4
Lead	12.39 gm/cm² x 4 x 4	0.724 ± 0.030	1
Cadmium	12.24 gm/cm² x 4 x 4	0.599 ± 0.015	5
Copper	11.74 gm/cm² x 4 x 4	0.411 ± 0.020	2
Copper	11.48 gm/cm² x 4 x 4	0.402 ± 0.018	2
Aluminum	11.92 gm/cm² x 4 x 4	0.292 ± 0.015	4
Carbon	7.67 gm/cm² x 4 x 4	0.164 ± 0.014	2
Beryllium	10.20 gm/cm² x 4 x 6	0.438 ± 0.015	4
Lithium	4-1/2 x 4 dia.	0.208 ± 0.012	1

* nondifferential targets

Table VI

Laterally-Infinite Target Yields for 190-Mev Deuterons

Target	Yield (neutrons per incident deuteron)	No. of Runs
(3-3/4 C + 10-1/8 U) x 24 x 24	2.3 ± 1.4	2
4 x 12 x 15 Be	0.99 ± 0.05	1
10 x 12 x 15 Be	1.23 ± 0.06	2
22 x 12 x 15 Be	1.25 ± 0.06	1
4 x 24 x 24 Be	0.98 ± 0.05	2
4 x 24 x 24 Be*	0.94 ± 0.05	1
(4 Be + 5-5/8 U) x 24 x 24	2.72 ± 0.13	4
(4 Be + 10-1/8 U) x 24 x 24	2.40 ± 0.12	5
(4 Be* + 5-5/8 U†) x 24 x 24	2.08 ± 0.10	4
(4 Be* + 10-1/8 U†) x 24 x 24	1.90 ± 0.10	3
(4 Be* + 10-1/8 U) x 24 x 24	1.93 ± 0.10	2
(3 Be* + 5-5/8 U†) x 24 x 24	2.10 ± 0.10	2
5-5/8 x 24 x 24 U	3.46 ± 0.17	2
10-1/8 x 24 x 24 U	3.19 ± 0.18	1
(5/8 U** + 10-1/8 U†) x 24 x 24	2.98 ± 0.13	5
5 x 36 x 36††	2.36 ± 0.12	4

* Moderated Primary: 1/4 Al between each 1 Be
** Moderated Primary: 0.022 Al between each 1/16 U
† Moderated Secondary: 3/16 Al between each 1-1/8
†† Moderated Target: First 1 of U: 3/32 CH_2 between each 1/16 U;
Second 4 of U: 3/32 CH_2 surrounding 1/2 x 1/2 x 36 bars of U.

Note: Because of increased neutron leakage, the measurements in the 12-inch $MnSO_4$ tank may tend to be 5 percent higher than those in the 18-inch tank (UCRL-1903, p. 84).

This work was performed under the auspices of the U. S. Atomic Energy Commission.

END